(12) UK Patent Application (19) GB (11) 2 012 966 A

(21) Application No **7850374**
(22) Date of filing **29 Dec 1978**
(23) Claims filed **29 Dec 1978**
(30) Priority data
(31) **41530/77**
(32) **6 Oct 1977**
(33) **United Kingdom (GB)**
(43) Application published
1 Aug 1979
(51) **INT CL²**
G01N 27/82
(52) Domestic classification
G1N 19B2G5 19D10
19F7D1 19H1M 19H1X
19H7B2 19X1 19X5
(56) Documents cited
GB 1386506
GB 1368326
GB 1261346
GB 1023067
GB 936033
GB 936015
GB 306232
GB 283256
(58) Field of search
G1N

(71) Applicants
Health and Safety Executive, Baynards House, 1 Chepstow Place, Westbourne Grove, London, England
(72) Inventor
Brian Gerald Marchent
(74) Agent
C. Goodman

(54) Apparatus for non-destructive testing of elongate objects

(57) Apparatus of the above kind includes magnetising means 1, 2 having pole pieces 6 arranged to surround and to provide a constant magnetising force along a length of the elongated object 5 e.g. a wire rope longitudinally of its axis and magnetic sensor means 7 e.g. Hall effect sensors under the pole pieces in air gaps 8 for measuring the magnetic field coupled into the object to provide by comparison with the level associated with the known object in good condition an indication of the condition i.e. cross-sectional area of the used object. To detect broken wires a sensor collar 23 is mounted around wire 5 which supports radial and longitudinally arranged Hall effect sensors.

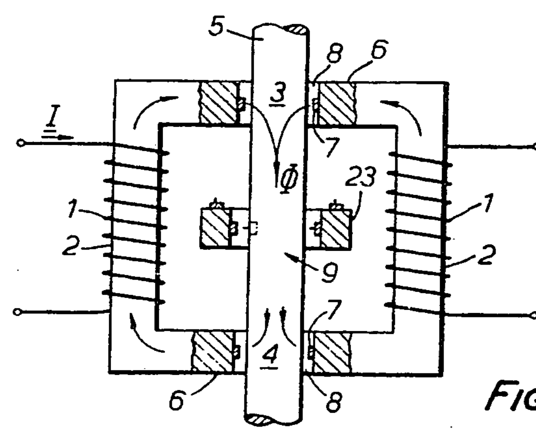

FIG. 2.

GB 2 012 966 A

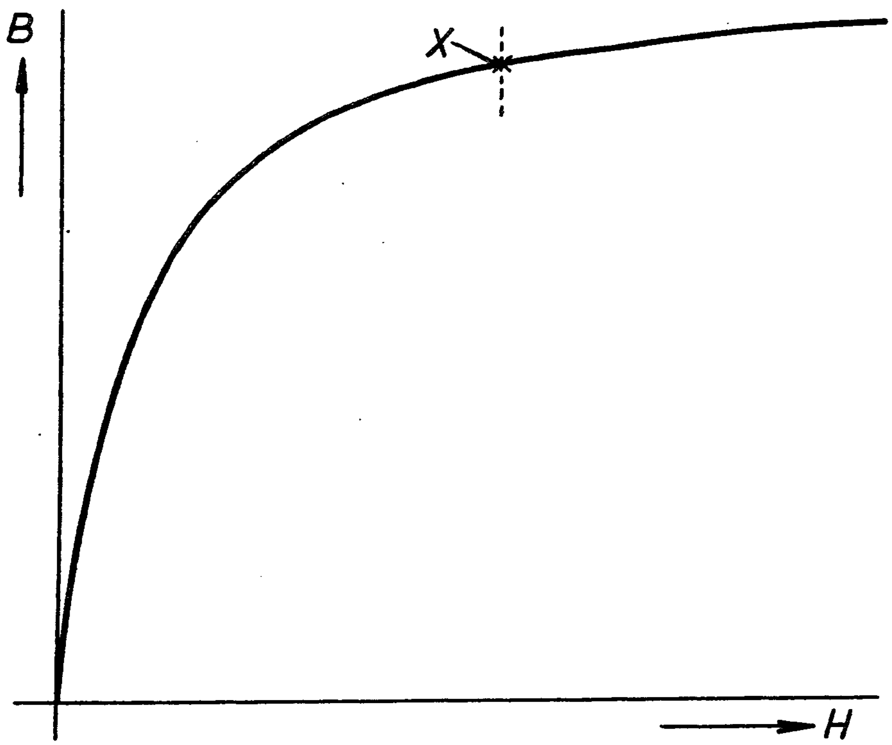

FIG. 1.

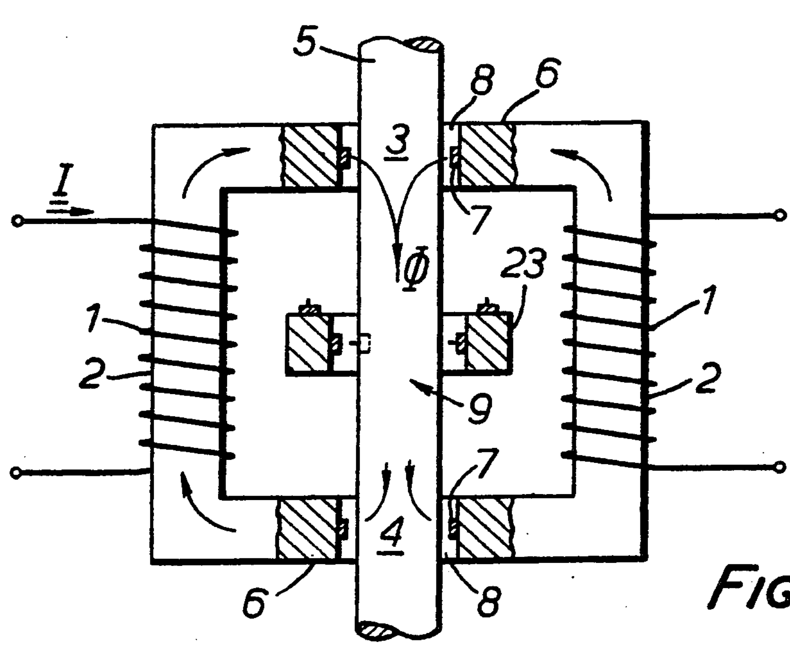

FIG. 2.

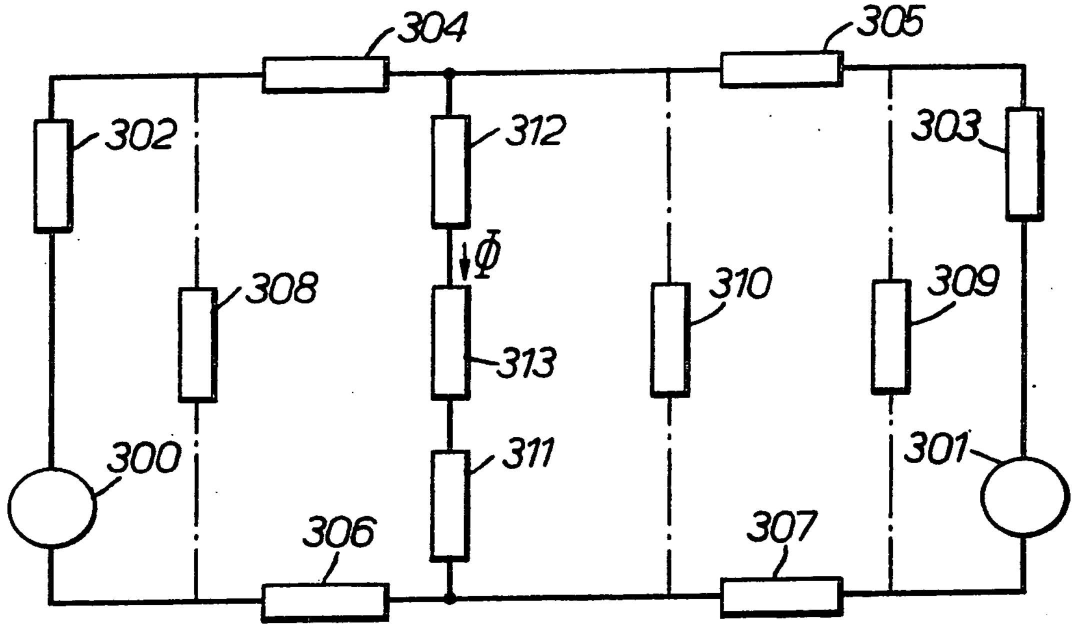
304
305
302
312
303
Φ
308
310
309
313
311
300
301
306
307

FIG. 3.

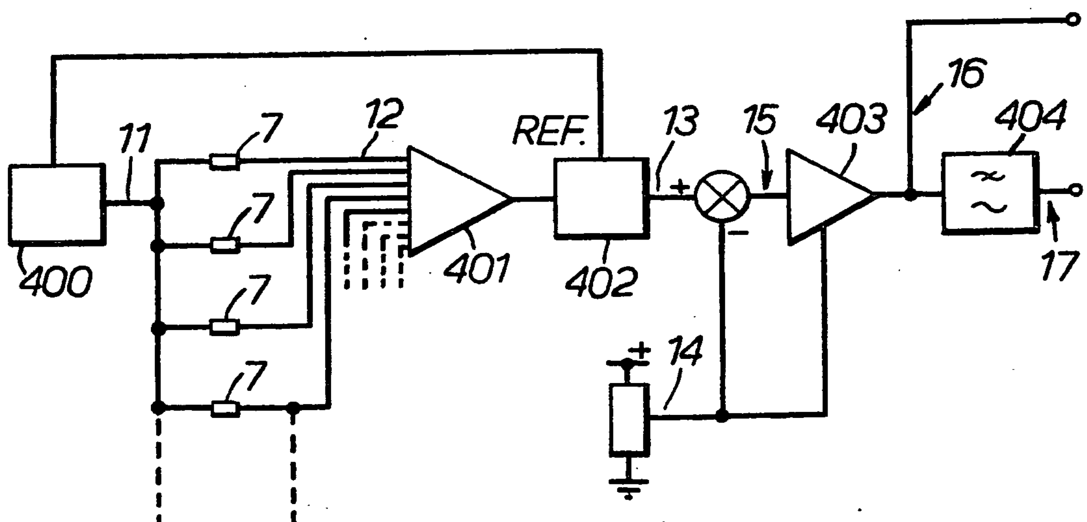
16
404
11
7
12
REF.
13
15
403
+
−
7
401
402
400
17
7
14
+
7

FIG. 4.

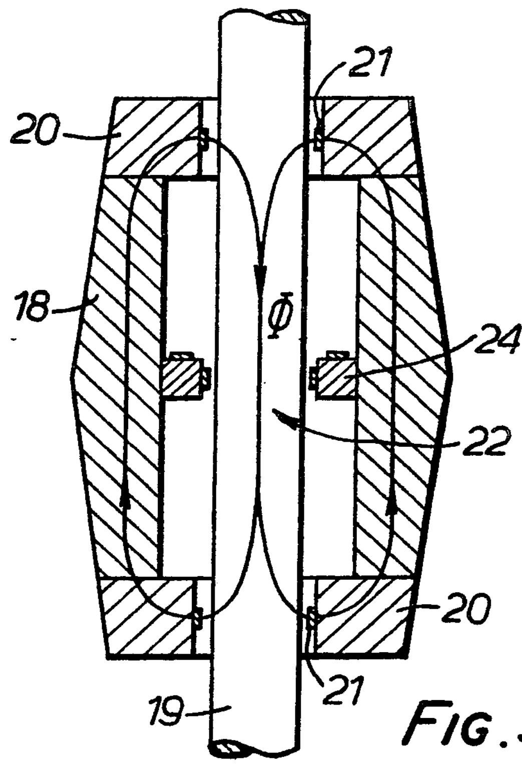

FIG. 5.

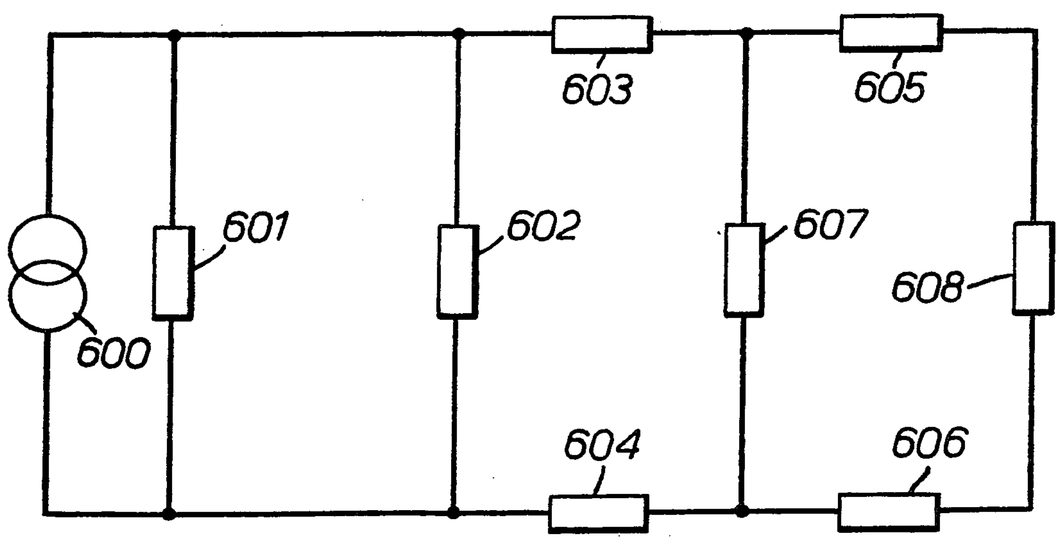

FIG. 6.

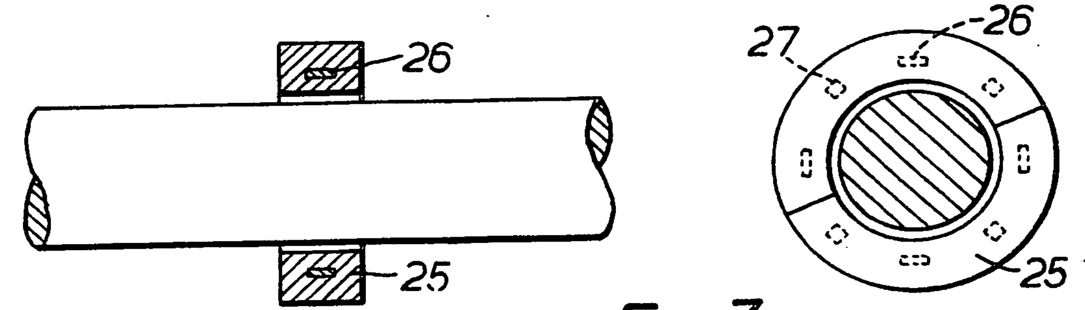

FIG. 7.

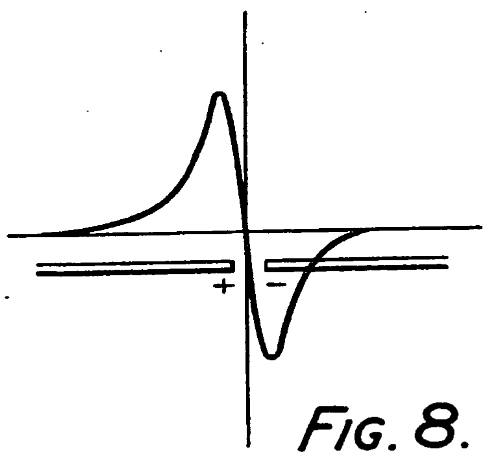

FIG. 8.

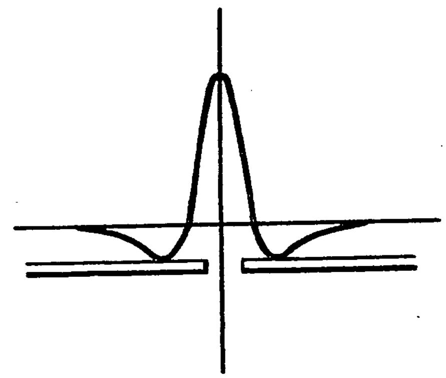

FIG. 9.

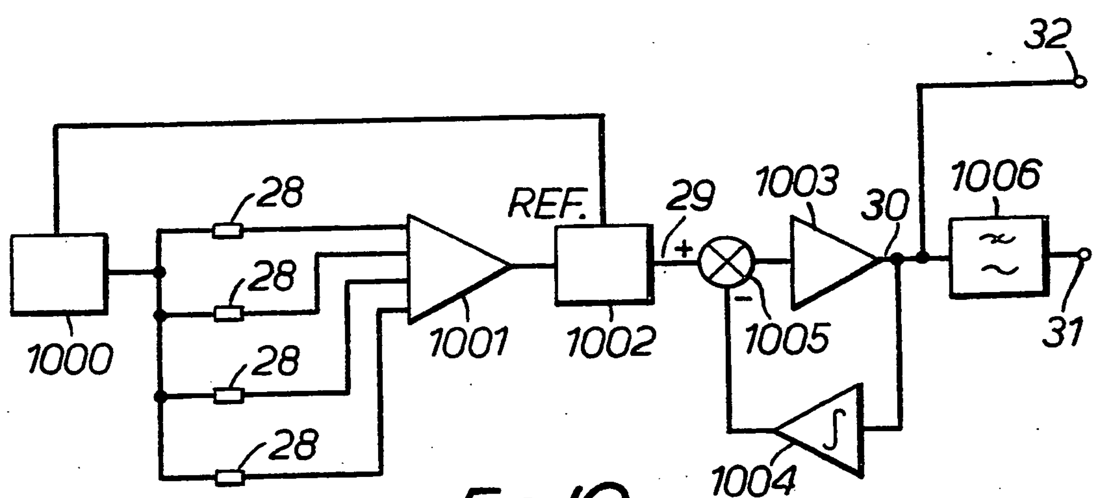

FIG. 10.

SPECIFICATION

Improvements in or relating to apparatus for non-destructive testing of elongate objects

This invention relates to apparatus for non-destructive testing of elongated ferromagnetic objects such as wire rope and has a special reference to the detection of loss of steel cross-sectional area and loss of effective strength due to flaws in the object or broken wires in the case of a wire rope. In the case of wire rope the loss of steel cross-sectional area can be due to wear or corrosion and it is not only important for safety considerations to be able to obtain a measure of strength reduction in the rope, but a reliable method will in many cases allow a rope to continue in use where imperical determination of life would have caused it to be scrapped prematurely.

According to the invention, apparatus of the above kind includes magnetising means having pole pieces arranged to surround and to provide a substantially constant magnetising force along a length of the elongated object longitudinally of its axis and magnetic sensor means under the pole pieces for measuring the magnetic field coupled into the object to provide by comparison with the level associated with the known object in good condition an indication of the condition of the used object.

The invention also contemplates the provision of magnetic sensors in a collar around the object at a position intermediate of the pole pieces. Such sensors may be radial to provide an indication of the passage through the collar of a part of the object in which there is a discontinuity such as a broken wire in a wire rope.

The sensors referred to above may in all cases be Hall effect devices for both the pole piece sensors and the sensors under the collar and while there may be some upper limit to speed of the object through the apparatus beyond which reliable indications or measurements are not obtained, the measurements or indications obtained by the apparatus of the invention are virtually independent of speed. Steel cross sectional measurement can be taken even at zero speed of the object through the apparatus.

Although the invention may be applied to the testing of elongated ferromagnetic objects, it will be convenient to describe it in relation to wire rope and it will be understood that references to wire rope are intended to refer also, where applicable to other elongated ferromagnetic objects.

Embodiments of the present invention will now be described, by way of example with reference to the accompanying drawings, in which:—

Figure 1 shows a typical magnetisation characteristic for the steel of a wire rope,

Figure 2 shows diagrammatically a first embodiment of the present invention using an electromagnet for rope magnetisation,

Figure 3 shows the equivalent magnetic circuit of the apparatus of Figure 2,

Figure 4 shows one possible form of electronic circuitry associated with the magnetic pole piece sensors of Figure 2,

Figure 5 shows diagrammatically a second embodiment of the present invention using a permanent magnet for rope magnetisation,

Figure 6 shows the equivalent magnetic circuit of the apparatus of Figure 5,

Figure 7 shows the intermediate sensor collar used in the first and second embodiment of the invention,

Figure 8 shows an output signal of the collar of Figure 7 as detected from a short gap length break in a wire in a wire rope by the radial sensors,

Figure 9 shows a similar output signal of the collar of Figure 7 as detected by the longitudinal sensors and

Figure 10 shows one possible form of electronic circuitry associated with the sensor output from the collar of Figure 7.

The apparatus as shown in Figure 2 applies a magnetic field to a length of wire rope which is pulled along in its longitudinal direction. Alternatively the apparatus may be moved along a fixed rope. The points at which the magnetic field is applied to the wire rope are chosen at sufficient distance apart to ensure that the main part of the rope between these points carries a substantially uniform magnetic flux density over the rope steel cross-section. Due to the constant magnetising force between the two points the magnetic flux density over the rope steel cross-section is defined by a fixed point X (Figure 1) on the magnetisation curve for the rope steel. If sufficient magnetising force H is used, approaching magnetic saturation, as shown in Figure 1 of the accompanying drawings, then the flux density B is little effected by any previous magnetisation of the rope or any small change in magnetising force H. The flux density in the rope is thus constant for a given material and the magnetic flux between the two points on the rope is directly proportional to steel cross-sectional area of the rope. This magnetic flux can be measured as it couples into or out of the rope via the air gap under the faces of the pole pieces of the electromagnet above these points on the rope. Some fringing field exists between the free ends of the rope outside the instrument which may slightly distort the linear relationship between pole flux and rope steel cross-sectional area but this will not otherwise affect the detection of rope steel cross-sectional area, in particular detection of change of rope steel cross-sectional area.

One embodiment of the invention is shown in Figure 2 and 3 of the drawings. In this an electromagnet consisting of drive coils 1 wound on two separate yoke bars 2 provide a constant magnetising force between two points 3 and 4 on a rope 5 with magnetic flux being coupled into the rope via the pole pieces 6. The electromagnet could however be wound on one, or four yokes. The electromagnet can be split along its axes of symmetry to fit over the rope in situ. Radial magnetic sensors 7 in the air gap 8 under one or both of the pole pieces provide a measure of the

magnetic flux, and thus the mean steel cross-sectional area of the rope 9 between the pole pieces. The direction of the flux is indicated by the arrows. A number of radial sensors 7 are used under one or both pole pieces equally spaced around their inner diameter so the sum of their outputs can be taken to compensate for some rope eccentricity within the pole piece. Hall effect sensors are used for the magnetic sensors because of their small size, suitable magnetic sensing range, and their ability to measure absolute flux density levels.

Figure 3 is a diagrammatic representation of the magnetic circuit of this arrangement in which 300, 301 represents the magnet motive force of the two coils and 302, 303 the reluctances of their respective yokes. The reluctances of pole pieces 6 are represented by 304, 305, 306 and 307, the leakage field of the coils are shown by dotted connections to 308, 309 respectively and the leakage from pole to pole is represented by 310. The reluctances of the air gap between the pole pieces and the rope are represented by 311, 312 and the magnetic effect of the rope is represented by 313 with the flux direction being indicated by the arrow and its magnitude being I.

A block diagram of one possible form of electronic circuitry for steel cross-sectional area detection is shown in Figure 4. The sensors under the pole pieces are supplied with a drive signal 11 consisting of a square wave at around 100KHz from a generator 400, to provide the control current for all the pole piece Hall effect sensors 7. The outputs 12 of all the pole piece sensors, proportional to magnetic field, are summed in an amplifier 401 and synchronously detected in a detector 402 to give an output 13 proportional to the mean magnetic field level detected by the pole piece sensors 7. It should be noted that the sensors 7 under the second pole piece 6 are reversed in sensing direction. A reference voltage REF is fed to the detector 402 from the generator 400. A D.C. voltage set up manually 14 is subtracted from the detector output 13 to give an output 15 indicating change of steel cross-sectional area. If this D.C. voltage is calibrated then the calibration setting to give zero voltage at 15 can be used to indicate directly rope steel cross-sectional area. Alternatively, if the D.C. Voltage is set to give zero voltage at 15 on a good section of the rope then any later voltage at 15 from the same rope will indicate change in steel cross-sectional area from that good section of rope. The voltage at 15 can be amplified via a gain controlled amplifier 403 controlled by the same D.C. voltage 14 to give an output 16 representing percentage change in rope steel cross-sectional area from that of the good section of the same rope. A low pass filter 404 can also be used to give a cleaner output 17 free of noise, in particular high frequency noise produced even by the good rope. The final output of the percentage change in steel cross-sectional area can be observed directly as an analogue output or compared to threshold levels to indicate excessive wear or presence of a splice.

The requirement of steel cross-sectional area measurement is a constant magnetising force between two points on the rope. This can alternatively be supplied by a permanent magnet.

Another aspect of the invention, therefore, is the provision of a permanent magnet for rope magnetisation. This consists of a cylindrical hollow magnet enclosing the rope with soft iron pole pieces over two points on the rope to couple the magnetic flux into the rope. The magnet can be split along its axis to enable it to fit over the rope in situ. Radial magnetic sensors are contained as before under the pole pieces for steel cross-sectional area detection. Normally a permanent magnet will try to supply a constant magnetic flux and not a constant magnetising force to the rope. If a reasonable leakage flux is assumed around the permanent magnet, outside the rope then some stabilisation of the magnetising force is obtained. Also if a high magnetising force is used, approaching magnetic saturation, then the flux density in the rope is little affected by changes in the magnetising force on the rope. Thus a relationship of magnetic flux coupled into the rope, proportional to steel cross-sectional area, is still obtained.

An embodiment of this form of the invention is shown in Figures 5 and 6. In this a hollow cylindrical permanent magnet 18 magnetised along its length, split into two halves is assembled around the rope to be tested 19. The magnetic flux of the permanent magnet is coupled into the rope via the pole pieces 20. As before radial magnetic sensors 21 under the pole pieces are used to provide a measure of the steel cross-sectional area of the rope. Also the output signals can be processed in the same way as before and described in relation to Figure 4.

Figure 6 is a diagrammatic representation of the magnetic circuit of this arrangement, in which 600 represents the magnet recoil permanent flux, 601 the magnet recoil reluctance, 602 the magnet leakage reluctance, 603, 604 the pole reluctances 605, 606 the airgap reluctances, 607 the internal leakage reluctance between pole pieces and 608 the rope reluctance.

Another aspect of the invention is the use of Hall effect sensors for broken wire detection and rope magnetisation monitoring and measurement. Means of rope magnetisation as described in relation to Figure 2 or 5 is provided such that a section of the rope under test 5 or 19 is magnetised along its axis so that a substantially uniform magnetic flux flows along the length of the rope 9 or 22. A sensor collar 23 or 24 is mounted around the rope, concentric with the rope. This is shown in more detail in Figure 7. The collar 25 contains a number of radial Hall effect magnetic sensors 26 equally spaced around the collar circumference for broken wire detection. The collar may also contain longitudinal magnetic sensors 27 which can also be used for broken wire detection and also for detection of level of rope magnetisation. Thus it is possible to monitor the

magnetisation provided by the electromagnet or permanent magnet. The collar is usually split to enable it to fit, with the magnet, over the rope in situ.

The form of the output obtained from the collar magnetic sensors as a rope with a broken wire passes through the sensor collar is shown in Figure 8 for the radial sensors and Figure 9 for the longitudinal sensors. The amplitude of the magnetic field peak detected varies roughly as the cube of the distance from the wire break whilst its width is roughly proportional to distance from the wire break. Possible electronic circuitry for broken wire detection is shown in Figure 10. All the collar sensors 26, 27 are driven from a generator 1000 producing a square wave at around 100 KHz to provide the control current for the Hall effect sensors 28. Considering first the radial sensors 26 in place of 28 then all the radial Hall effect sensor outputs are summed in a summation amplifier 1001 and synchronously detected in a detector 1002 to given an output 29 proportional to the mean output from all the radial sensors. The summing process helps to eliminate noise from the rope. The output at 29 is fed to an amplifier 1003 via a summation device 1005 to give a suitable output dynamic range at 30. Integrator feedback via an integrator 1004 and summation device 1005 is used to provide A.C. coupling with a time constant of the order of a few seconds. The output at 30 may be filtered in a low pass filter 1006 to remove some rope noise, mainly due to the characteristics of the good rope, to give output 31. A non-filtered output 32 can also be provided. Output 31 can be viewed directly as an analogue signal or compared to a threshold level for broken wire detection.

The electronic circuit for the longitudinal sensors for broken wire detection is basically the same as for the radial sensors, Figure 10, but with sensors 27 in place of 28. If an indication of rope magnetisation is required then the voltage at point 29 for the longitudinal sensors can be used.

In a practical embodiment the apparatus is made in two similar parts which are preferably hinged. This allows a wire rope to be inserted into the apparatus or the apparatus fitted around a rope in situ. The apparatus may be self contained with the electronic circuitry being included together with the magnetic circuitry in two waterproof casings each casing being provided with one or more guide wheels or rollers to allow the wire rope to move freely through the apparatus.

The apparatus may be provided with a visual output e.g. a light display to indicate rope wear above a preset level and for a splice in the rope and/or a broken wire in the rope as the rope passes through the apparatus. Also a meter could be included on the apparatus to display the analogue outputs from steel cross-sectional output 17, Figure 4 and/or the break detection output 31, Figure 10. Alternatively, or additionally a multi-channel tape recorder for low frequency to D.C. analogue recording may be attached to the apparatus to record the above outputs with distance marker pulses to indicate their position along the rope. Finally, the detection of a broken wire and/or wear above a preset threshold and/or a splice could be used to cause the apparatus to operate a paint spray system to mark the rope.

CLAIMS

1. Apparatus for the non destructive testing of elongated ferromagnetic objects including magnetising means having pole pieces arranged to surround and to provide a substantially constant magnetising force along a length of an elongated ferromagnetic object longitudinally of its axis and magnetic sensor means under the pole pieces for measuring the magnetic field coupled into the object to provide, by comparison with the level associated with the known object in good condition, an indication of the condition of the used object.

2. Apparatus as claimed in claim 1 in which the magnetising means is an electromagnet.

3. Apparatus as claimed in claim 1 in which the magnetising means is a permanent magnet.

4. Apparatus as claimed in any one of claims 1 to 3 in which said pole pieces are in two sets, a predetermined distance apart and in which further magnetic sensors are provided in a collar surrounding the object at a position intermediate said two sets of pole pieces.

5. Apparatus as claimed in claim 4 in which the further magnetic sensors are radial within said collar to provide an indication of the passage through the collar of a part of the object in which there is a discontinuity, and including electronic means associated with said further sensors for processing the output signals from said sensors to provide an indication of any discontinuity.

6. Apparatus as claimed in claim 5 including recording means associated with said electronic means for recording the discontinuities in said object as said object is moved past said magnetic sensors.

7. Apparatus as claimed in any preceding claim, in which the magnetic sensors are Hall effect devices.

8. Apparatus for the non-destructive testing of elongated ferromagnetic objects substantially as described with reference to the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1979. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.